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In-situ monitoring of ATP hydrolysis at high pressure and temperature: exploring the limits of life

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The quest to explore our planet led to the discovery of new biological communities in geological extreme environments. Hot springs, deep oceanic sediments, and hydrothermal vents are great examples of a variety of fascinating habitats. Survival of organisms is possible through unique adaptations to each environment. Biological-geological interaction enables life up to 120 °C and 300 MPa. Experimental studies, albeit controversial, expanded the pressure range to gigapascal.

The exergonic enzymatic hydrolysis of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) is found at the root of all known metabolic systems. At elevated temperatures, the enhanced kinetics of the non-enzymatic hydrolysis counteracts this metabolic reaction. Its rate constant and the related half-life is a good measure of the kinetic stability of ATP, hence of its biochemical availability. An understanding of the physicochemical controls on the rate constant provides us one step further towards the limits of life.

We used a combination of a high-pressure autoclave and a hydrothermal diamond anvil cell attached to a Raman spectrometer for in-situ investigation of pressure- temperature- ionic composition effects on the kinetics of non-enzymatic ATP hydrolysis. Early findings showed half-lives of 2-5 mins at 120 °C and vapor pressure. All results so far indicated an Arrhenian relationship over the T-interval of 80 – 120 °C. Below 0.5 GPa, the effect of pressure is vanishingly low. At 100 °C, an increase in pressure resulted in a decrease of the half-lives: from roughly 20 mins at 0.5 GPa, to 2 mins at 1.5 GPa. Above 2 GPa, the half-life was far below the detection limit. An addition of NaCl is lowering the T-dependence and thus the activation energy.

Preliminary observations in combination with a maximum biological turnover rate of 1.5 s^{-1} for ATP would suggest a possibility for ATP-based life up to 195 °C in pure ATP-H_2O systems at vapor pressure (Moeller et al. 2022). This temperature limit is lowered by additional pressure or elevated by the presence of NaCl, respectively.

Moeller, C. Schmidt, F. Guyot and M. Wilke, "Hydrolysis rate constants of ATP determined in situ at elevated temperatures" Biophysical Chemistry, vol. 290, 2022.